Tectonic setting and hydrocarbon habitat of the Romanian external Carpathians

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ABSTRACT

The external part of the Romanian Carpathians hosts three more or less discrete hydrocarbon provinces, namely the Bistrita-Trotus and the Carpathian Bend provinces of the East Carpathians and the Getic Depression province of the Southern Carpathians. All three provinces appear to be intimately related to Oligocene-Early Miocene oil-prone source rocks; however, a contribution from Cretaceous source rocks cannot be excluded. The Bistrita-Trotus and the Carpathian Bend provinces are characterized by thin-skinned nappes, involving Cretaceous, Paleogene and Neogene sediments, which override a deeply subsided autochthonous foreland. The Getic foreland basin contains Eocene to Pliocene molasse-type sediments which are involved in basement-controlled compressional and transpressional structures.

In the Bistrita-Trotus province, mostly shallow, small and medium fields produce from Paleogene flysch of the Marginal Folds nappe involved in complex structures beneath the Tarcau nappe.

In the prolific Carpathian Bend province, Oligocene to Pliocene shallow marine, deltaic series, involved in the Tarcau, Marginal Folds and Subcarpathian nappes, contain multiple reservoir-seal pairs. Structural traps are associated with all nappe units. Unconformities, related to the different compressional phases, provide for additional traps. Established fields are contained in relatively shallow structures which attained their present configuration during the terminal Pliocene deformation phase.

In the Getic Depression, oil accumulations are closely related to the distribution of Paleogene series; gas-prone Mio-Pliocene source rocks charged Late Miocene and Pliocene reservoirs, involved in structural and combined stratigraphic/structural traps of the southern part of the Getic Depression.

Deep seated structures of the external Carpathians fold-and-thrust belt have probably a considerable hydrocarbon potential; however, definition of such prospects requires improved reflection-seismic resolution. Subthrust plays, aiming at the sedimentary cover of the underthrusted foreland, are restricted to the northern part of the Eastern Carpathians.

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INTRODUCTION

Statistics show that Romania is among the first oil producing countries of the world. First oil production has been recorded in 1857 at a rate of 275 tons/year. However, the extraction of crude at Mosoarele, Poieni, Doftana and Pacureti, located in the Romanian provinces of Moldavia and Valachia, has been mentioned by foreign travellers already since the first half of the 16th century.

In 1861, the first well was dug mechanically at Mosoarele, Moldavia. In 1900, Romania was the third largest oil producer of the world with an annual production of $0.3 \cdot 10^6$ tons/year. In 1953-1955, the oil output of Romania was 9-$10 \cdot 10^6$ tons/year, and in 1976 a maximum oil output of $14.6 \cdot 10^6$ tons was achieved (Fig. 1). After 1976, crude production in Romania decreased gradually and more rapidly during the last years. In 1994, oil production was at the level of $6.4 \cdot 10^6$ tons.

For a better understanding of the geology of Romanian and the evaluation of prospective areas detailed geological maps and synthesis have been drawn up over the years. All geophysical methods were applied in regional and detailed research efforts, especially seismic ones. In onshore prospective areas, the density of available reflection-seismic coverage amounts to about 1.75 km profiles per km^2 and in the Black Sea off-shore to about 2.4 km profiles per km^2.

About 400 wells deeper than 3500 meters have been drilled in an effort to explore the deep structure and hydrocarbon potential of the country. The deepest well of Romania was drilled in the Baicoi field and reached a total depth of 7025 meters.

The Carpathian fold-and-thrust belt is the least explored part of Romania. Its very roughly topographic relief presents difficulties in the acquisition of reflection-seismic lines and its very complicated internal structure is often difficult to resolve.

TECTONIC SETTING

During the Alpine evolution of Romania, two distinct depositional areas evolved in the external

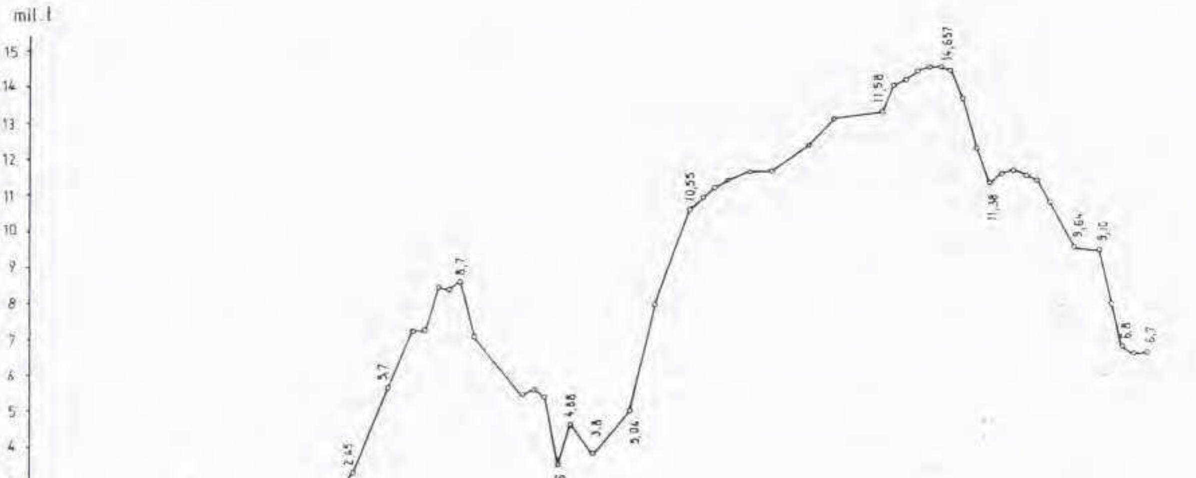


FIG. 1. Oil production of Romania during the period 1900-1993.

zone of the Carpathians, namely the Paleogene flysch and Neogene molasse basin of the Eastern Carpathians and the Paleogene and Neogene molasse basin of the Southern Carpathians (Getic Depression). Both basins were compressionally deformed during the successive Neogene Styrian (20-15.5 Ma), Moldavian (12-11 Ma) and Valachian (1.5-1 Ma) phases, giving rise to the development of a system of nappes and thrust sheets which form the external Moldavides. During these deformation phases, the flysch and molasse series were folded, faulted and thrusted in sequence over the foreland, formed by the Moldavian, Scythian and Moesian platforms (Fig. 2).

In the Eastern Carpathians, orogenic movements at the end of the Paleogene and the beginning of the Neogene (Older Styrian phase, 20-18 Ma) were accompanied by intensified uplift of the internal Moldavides and the development of a rapidly subsiding foreland basin (Sandulescu, 1988). During the Younger Styrian phase (15.5 Ma), coinciding with the beginning of the Badenian, the Tarcau and Marginal Folds nappes were emplaced; this was accompanied by the development of evaporitic conditions in the foredeep basin. During the Early Sarmatian Moldavian pulse, the entire package of Paleogene and Neogene nappes was underthrusted by the foreland platforms, which form the autochthon of the Subcarpathian, Marginal Folds and Tarcau nappes, both in the Eastern and Southern Carpathians.

Based on geophysical data and the results of deep wells, the autochthonous foreland extends a considerable distance beneath the external nappes of the Carpathians. Minimum figures are 20 km in the Moldova Valley, 30 km in the Bistrita and Trotus valleys, 15 km in the Prahova Valley and 10 km in the Olt Valley (Figs. 2 and 3). Beneath the external Carpathian nappes, the autochthonous foreland is dissected by a system of basin parallel, predominantly synthetic normal faults and transverse faults which were active during its early Sarmatian rapid subsidence (Dicea, 1967, 1995; Dicea and Tomescu, 1969). In the Eastern Carpathians, the main basin parallel, synthetic faults are the Campulung Moldovenesc, Solca and Siret faults; transverse faults generally coincide with the Bistrita, Trotus, Putna and Buzau valleys (Fig. 4).

Although these faults affected only the autochthonous foreland and its sedimentary cover, the structural relief generated by these faults influenced the architecture of the overlying nappes and folds. For instance, between Bistrita and Putna of Vrancea valleys, where the autochthonous platform is located at depths greater than 5500 meters, several subunits of the Marginal Folds nappe are defined by surface and subsurface data. Their axes can be followed over tens of kilometres, both at the surface and beneath the Tarcau nappe (Fig. 5). Based on this criterion, most of the oil and gas accumulations of the Eastern Carpathians were discovered. However, north of the Bistrita Valley, the autochthon rises to depths of 4000 to 3000 m. In this area, the high position of the platform blocked part of the Marginal Folds nappes west of the Gura Humorului-Bicaz threshold (Fig. 3). Correspondingly, the flysch formations of the Marginal Folds nappe were intensely deformed and in some areas, particularly north of the Cracau Valley, small and thin slices of the Marginal Folds nappe occur beneath and in front of the Tarcau nappe. Further north, the continuity of folds is difficult to follow from half-windows. North of the Moldova Valley, the Marginal Folds nappe was encountered only to the west of this foreland threshold as one or two slivers beneath and in front of the Tarcau nappe (Fig. 3). In the border area towards the Ukraine (Suceava Valley), the platform deepens again and several superimposed subunits are evident beneath and in front of the Tarcau nappe (Fig. 6; Gluschko and Kruglov,1971).

South of Slanic-Oituz and Vrancea half-windows (Fig. 7, section F), the Marginal Folds nappe is covered by the Tarcau nappe, the thickness of which varies between 2000 and 5000 meters, as indicated by well data. Between Slanic of Buzau and the Dambovita valleys, in the area where the Carpathian deformation front swings around into a western direction, Sarmatian-Pliocene molasse sediments cover the Paleogene flysch units up to the Cretaceous flysch nappes (Fig. 7, section I and Fig. 8). This series attains thicknesses of over 5000 m and thins eastward towards the foreland. Sarmatian-Pliocene series record the Valachian deformation phase which gave rise to the development of a series of hydrocarbon accumulations, structurally trapped in Paleogene strata of the Tarcau and Marginal Folds nappes (Fig. 7, section F).

Between the Dambovita and Danube rivers, the South-Carpathian foredeep is characterized by

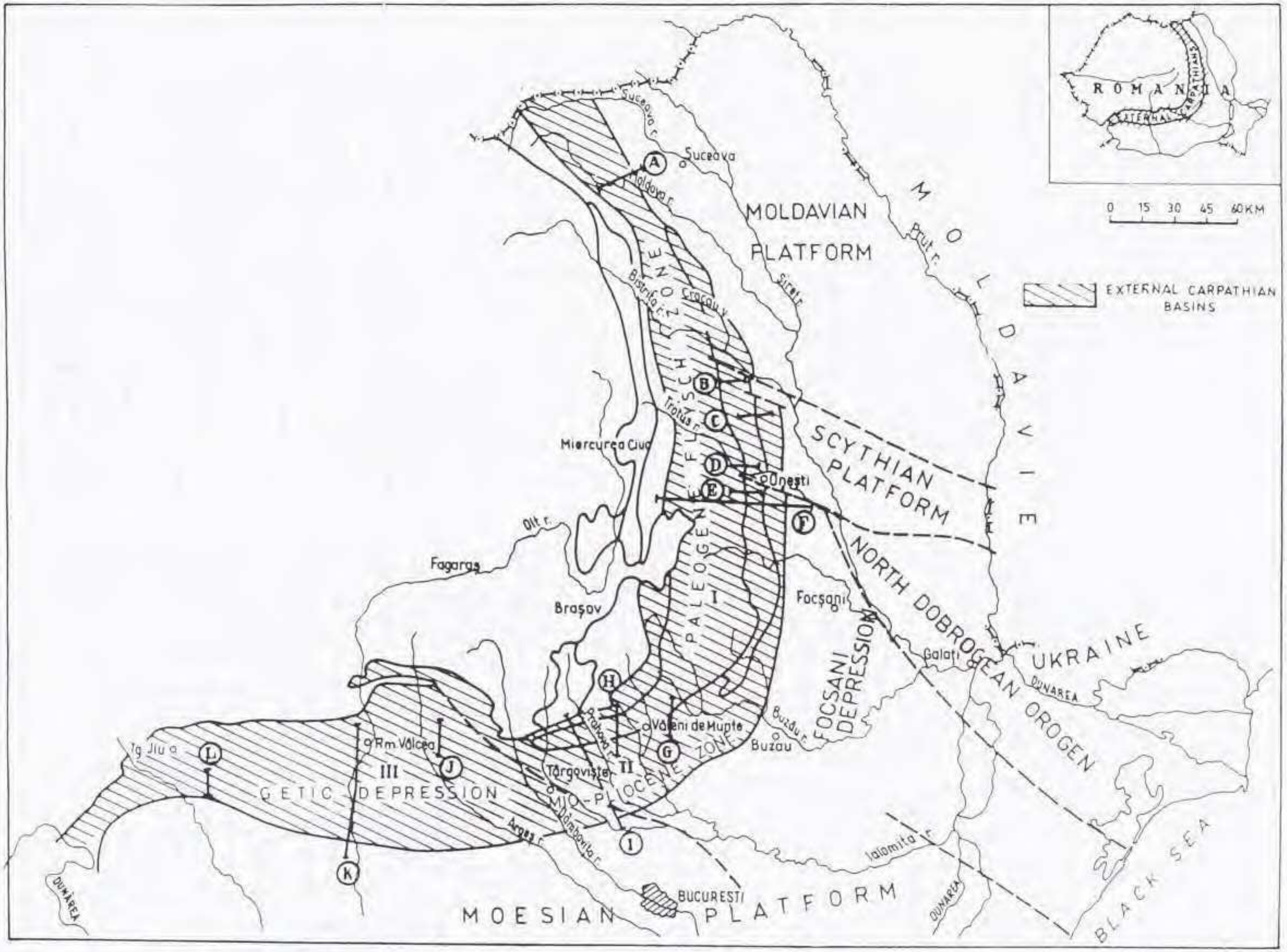


FIG. 2. Tectonic sketch map of Romanian External Carpathians (after Geological Institute of Romania), showing location of cross-sections A to L.

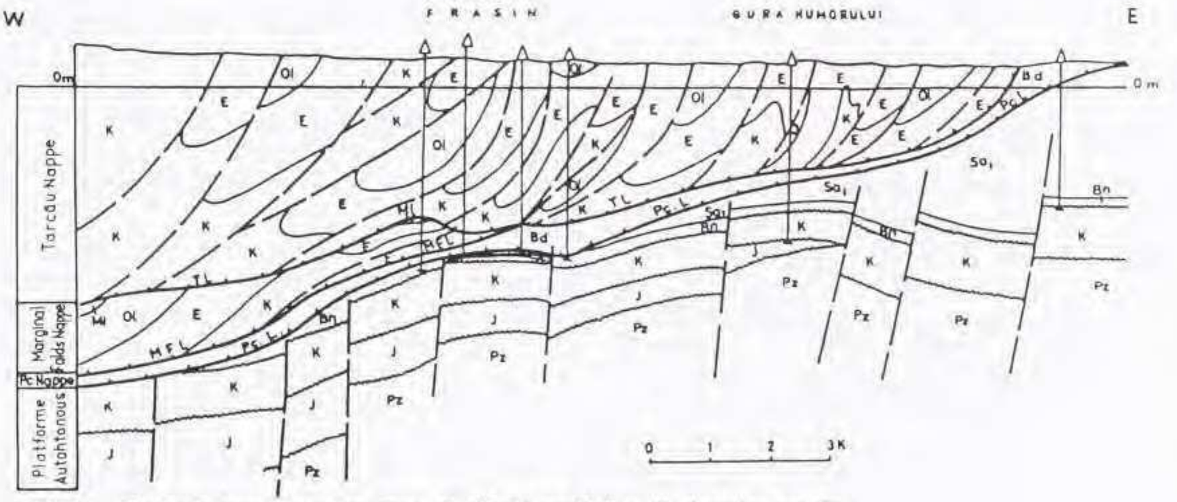


FIG. 3. Geological cross section along the Moldova Valley (for location see Fig 2, trace A). Pz - Palaeozoic, J - Jurassic, K - Cretaceous, E - Eocene, O - Oligocene, Mi - Miocene, Bd - Burdigalian, Bn - Badenian, Sa - Sarmatian, T.L. -Tarcau Line, M.F.L. - Marginal Folds Line, P.C.L. - Pericarpathian Line

the thick Paleogene and Neogene molasse deposits of the Getic Depression (Fig. 7, section K). Northward, Neogene series overstep the Cretaceous flysch nappes and the Mesozoic crystalline elements of the Southern Carpathians. Unlike in the Eastern Carpathians, the sedimentary fill of the Getic Depression is not involved in thin-skinned thrust sheets but in basement involving compressional and transpressional structures. The southern boundary of the Getic Depression is formed by the Pericarpathian fault, a major foreland verging upthrust (Fig. 7, section K and Fig. 19). The sedimentary series of the Getic Depression record the Older and Younger Styrian and the intra-Sarmatian Attic compressional phases; the Valachian phase was of minor importance in this area. On the external flank of the Getic Depression, Middle Sarmatian-Pliocene series overlap compressional structures in which Paleogene series are thrusted over Lower Sarmatian sediments (Fig. 7, section K). The area hosts a large number of hydrocarbon accumulations contained in structural traps.

PETROLEUM SYSTEMS

In the East-Carpathian Outer Moldavides, Paleogene and Neogene sediments attain thicknesses up to 5000 m. These consist predominantly of shaly and sandy series which contain multiple reservoir-seal pairs and major source rock intervals.

The most important source-rock of the East-Carpathian fold-and-thrust belt are the dyssodilic Rupelian-lower Burdigalian shales which have a total organic carbon content (TOC) ranging between 3.7 and 29.8%. In the domain of the Marginal Folds nappe, two main shale package occur within the Rupelian-lower Burdigalian interval (Fig. 9). The lower, Rupelian sequence is represented by the lower Menilite and lower Dyssodilic shales and their equivalents (shaly horizon of Pucioasa formation); these vary in thickness between 80 and 280 m. The upper, Chattian-lower Burdigalian interval consists of the upper Dyssodile shales, their equivalents (Vinetisu beds and Slon breccia) and the upper Menilites; it ranges in thickness between 50 and 100 m. These source-rock intervals are separated by the Kliwa Sandstone which was derived from the Carpathian foreland platform and presents an important reservoir. Both source-rock intervals, as well as the

Kliwa Sandstone, are also present in the Tarcau nappe. The latter contains additional reservoir-seal pairs in the Pliocene series (Fig. 9). Secondary source-rock intervals and reservoirs occur in the Eocene and Miocene sequences. In the Tarcau nappe, source-rock intervals are also present in the Cretaceous series and may have contributed to the accumulated oils (see Stefanescu and Baltes, this volume).

Reservoir parameters of the Kliwa Sandstone in the different parts of the external Carpathians and their foreland basins are summarized in Table 1. In the Marginal Folds nappe, to the north of Slanic Valley, the Kliwa Sandstones form a single, 20-170 m thick unit; a second objective horizon is formed by sandstones and conglomeratic beds occurring in a 60-120 m thick interval which straddles the Oligocene-Miocene boundary (Gura Soimului beds; Fig. 9). In the Carpathian Bend zone, the Kliwa Sandstones are only exposed in the Tarcau nappe where they are developed in two intervals. The Lower Kliwa horizon ranges in thickness between 100 and 150 m whereas the Upper Kliwa horizon attains thicknesses in the 200-300 m range (Fig. 9).

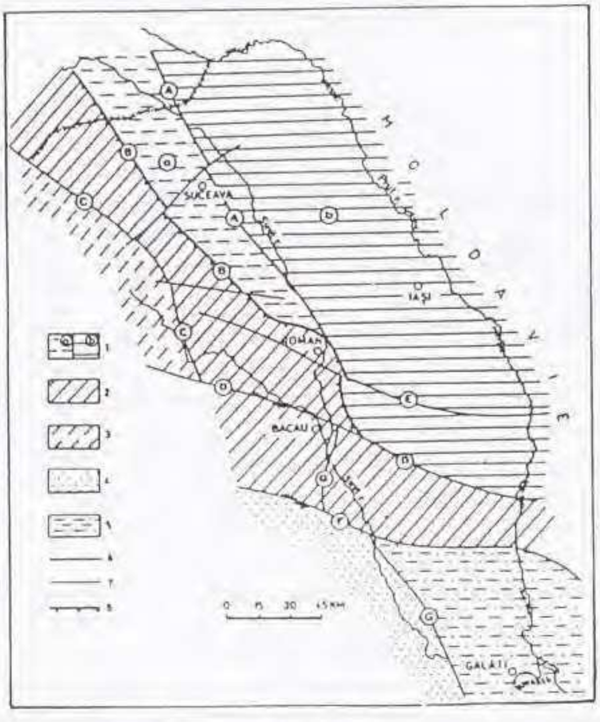


FIG. 4. Tectonic Sketch of East Carpathians Foreland (after Visarion and Sandulescu, 1981). A network of longitudinal and transverse faults having horizontal and vertical displacements, controls the architecture of flysch nappes. A-Siret Fault, B-Solca Fault, C-Campulung Moldovenesc-Bicaz Fault, D-Bistrita Fault, E-Vaslui Fault, F-Trotus Fault, G-Peceneaga-Camena Fault.

In the Getic Depression, source-rocks occur in the Late Cretaceous, Eocene, Oligocene and Sarmatian series (Fig. 9). The Oligocene series contains in its lower parts a 300-800 m thick sandstone and conglomerate sequence, referred to as "Horizon B", which forms an important reservoir; in some areas a predominantly shaly sand sequence, referred to as "Horizon A", is also developed. Facies analyses indicated that during the Oligocene, sands were shed into the Getic Depression mainly from the Southern Carpathians and, to a lesser degree, from the Moesian Platform (Fig. 10).

In the Carpathian Bend zone and in the Getic Depression, Oligocene, Miocene and Pliocene formations contain multiple reservoir-seal pairs. The facies development of individual reservoirs and sealing units was locally influenced by syndepositional tectonics. The Lower Burdigalian and Badenian salts provide the seal for many oil accumulations in the External Carpathians. Nevertheless, the Pliocene Meotian series is the most prolific objective in the Carpathians Bend zone and in the Getic Depression. Figure 11 provides a regional isopach map of the Meotian series on which sand-shale ratios are superimposed. The reservoirs properties of Meotian sands are summarized in Table 1.

In the External Carpathians, traps are mainly of the structural type and include anticlinal features, partly cut by thrust faults, and structures which are modified by the diapirism of salt. Stratigraphic pinch-out and unconformity traps play a subordinate role.

Tectonic unit	Stratigraphic Interval	Reservoir Rock	Thickness [m]	Porosity [%]	Permeability [mD]	Oil and Gas Fields
Tarcău Nappe	Eocene	Tarcău Sandstone	40 - 300	10 - 12	3 - 10	Păcuriţa, Văsieşti, Taşbuga, Stîrmini
	Oligocene	Kliwa Sandstone	200	16	50	Dofteana - Bogata
Marginal Folds Nappe	Oligocene	Kliwa Sandstone	50 - 200	10 - 20	10 - 120	Geamăna, Taşbuga, Asău, Moineşti
			150 -200	8	1 - 5	Ghelinţa
			350	25	400	Runcu - Buştenari
	Burdigalian	Sandstones and Conglomerates	20 - 250	7 - 18	2 - 120	Mihoc, Păcuriţa, Zemeş
Subcarpathian Nappe and Getic Depression	Eocene	Sandstones	45 - 80	15 - 21	8	Coseşti
	Oligocene	Kliwa Sandstone	50 - 250	13	38	Tescani
		Sands and Sandstones	10 - 70	20 - 27	10 - 500	Săpunari, Vîlcele, Merişani
	Burdigalian	Microconglomerates and Sandstones	50 - 100	12 - 27	27 - 170	Tescani, Alunu, Tg. Jiu
		Sands and Sandstones	10 - 250	15 - 28	3 - 2000	Cîmpeni, Teiş, Băbeni, Ţicleni
Foredeep and Getic Depression	Sarmatian	Sands and Sandstones	2 - 200	12 - 70	1 - 350	Ceptura,Boldeşti,Ţicleni
	Meotian	Sands and Sandstones	2 - 200	20 - 40	24 - 500	Băicoi,Moreni,Boldeşti, Bucşani, Ţicleni
	Dacian	Sands	10 - 40	20 - 37	18 - 2500	Boldeşti, Bucşani, Finta

TABLE 1. Reservoir Rocks in Eastern and Southern Carpathians

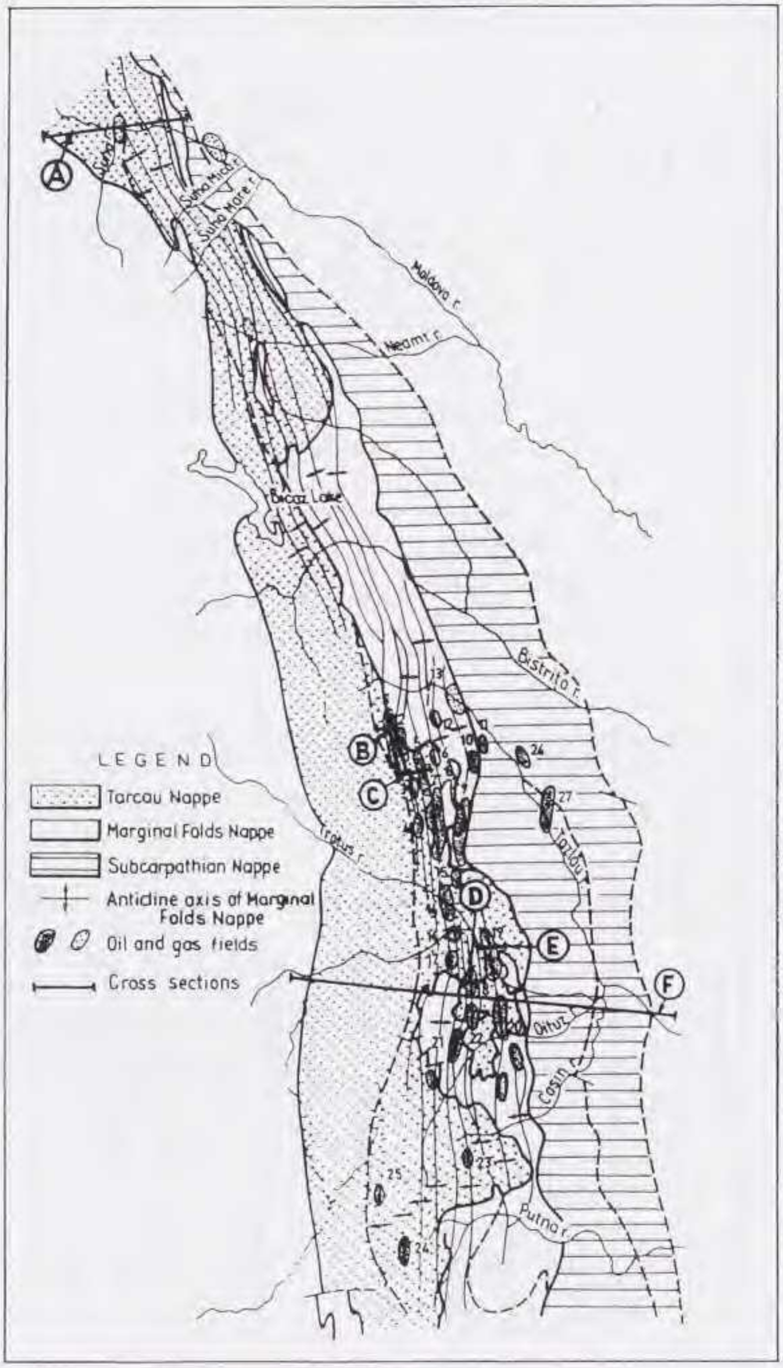


FIG. 5. Oil and gas fields from the Bistrita-Trotus Province. 1-Geamana, 2-Gropile lui Zaharache, 3-Chilii West, 4-Tasbuga, 5-Toporu-Chilii, 6-Arsita, 7-Zemes-Cilioaia, 8-Foale-Moinesti, 9-Uture-Moinesti oras, 10-Cucuieti, 11-Mihoc, 12-Frumoasa, 13-Tazlaul Mare, 14-Comanesti, 15-Vasiesti, 16-Darmanesti, 17-Doftenita, 18-Pacurita, 19-Dofteana-Bogata, 20-Slanic-Fierastrau, 21-Cerdac, 22-Slanic Bai, 23-Lepsa, 24-Ghelinta, 25-Ojdula, 26-Campeni, 27-Tescani.

MAIN PRODUCTIVE AREAS AND NEW PLAYS IN THE EXTERNAL CARPATHIANS

Main productive areas of the External Carpathians of Romania are the Paleogene Flysch Zone, the Mio-Pliocene Zone and the Getic Depression (Fig. 2).

Paleogene Flysch Zone

The Paleogene Flysch Zone comprises the Tarcau and Marginal Folds nappes of the Eastern Carpathians and the Carpathian Bend Zone (Fig. 7).

In the **Tarcau nappe**, conditions for generation, accumulation and preservation of hydrocarbons were not ideal. Only in the internal parts of this nappe, which were overridden by the Audia nappe, Oligocene source-rocks were buried to depths at which they entered the oil generation and partly even the gas generation window (Fig. 12a). Many potential anticlinal and thrusted anticline traps crop out and therefore have been destroyed by erosion. Only locally were oil accumulations discovered in the Tarcau nappe; these produce variably from the Oligocene Kliwa, the Oligocene-Lower Miocene Fusaru and the Eocene Tarcau sandstones. Generally, these accumulations are located above oil accumulations which produce from structures of the Marginal Folds nappe. Examples of such accumulations are the Zemes field in the Moldova region and the Geamana, Comanesti, Vasiesti, Pacurita and Dofteana-Bogata fields in the Tazlau-Oituz river area (Fig. 5).

Main hydrocarbon prospects of the Paleogene Flysch Zone are associated with the **Marginal Folds nappe** where it is covered by the Tarcau Nappe. In these areas, tectonic overburden provided for maturation of the Oligocene source-rocks (Fig. 12b). Most of these hydrocarbon accumulations are contained in massive or stacked reservoirs involved in thrusted folds and faulted anticlines; there are also examples of stratiform accumulations, sealed by faults or salt layers, and unconformity traps. Accumulations are concentrated along major structural axes which project northward and southward from half-windows in the Tarcau nappe.

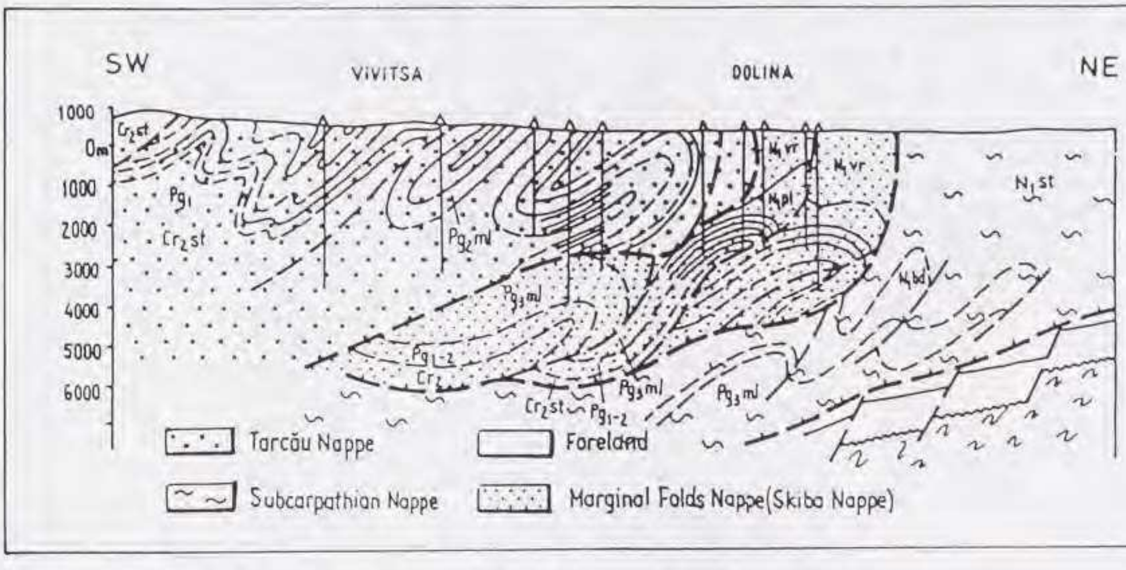


FIG. 6. Vitvitsa-Dolina geological cross-section, Ukrainian border area (after Gluschko and Kruglov, 1971). J_{2+3}-Middle-Upper Jurassic, Cr_2-Middle Cretaceous, Pg_1-early Paleogene, Pg_{1+2}-early-middle Paleogene, Pg_3ml- late Paleogene (Oligocene) Menilites, N_1pl-early Miocene Polianski Formation, N_1vr-early Neogene Vorotasce Formation, N_1db-early Neogene Dobrotov Formation, N_{st}-early Neogene Stebnik Formation. (for location see Fig. 2, trace A)

FIG. 7. Cross sections through External Carpathians (for locations see Fig. 2 traces F, I and K).

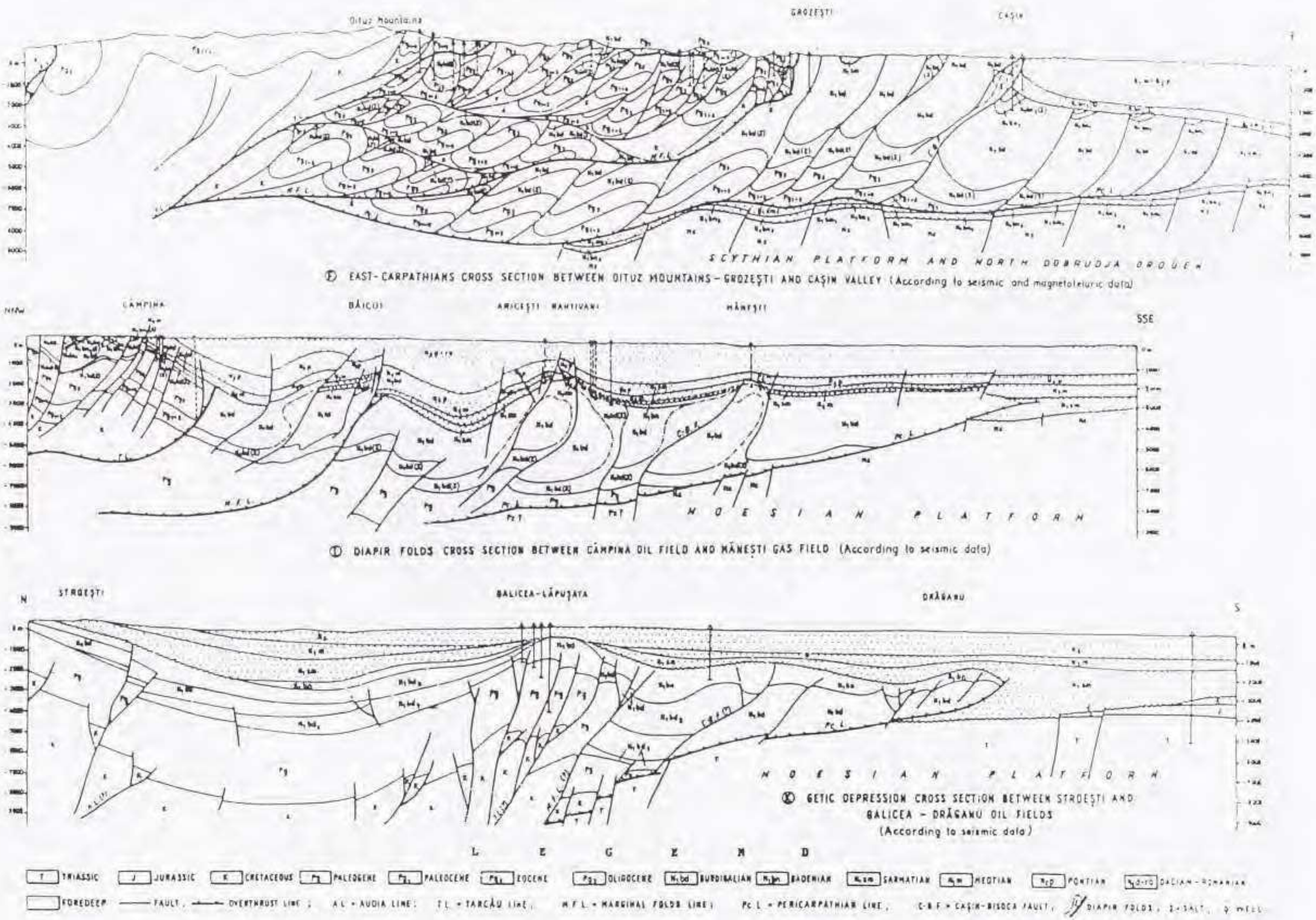


FIG. 8. Geological map of Mio-Pliocene Zone (from Romania lithostratigraphic map, after Patrut et al.,1973). G-I- Cross sections.

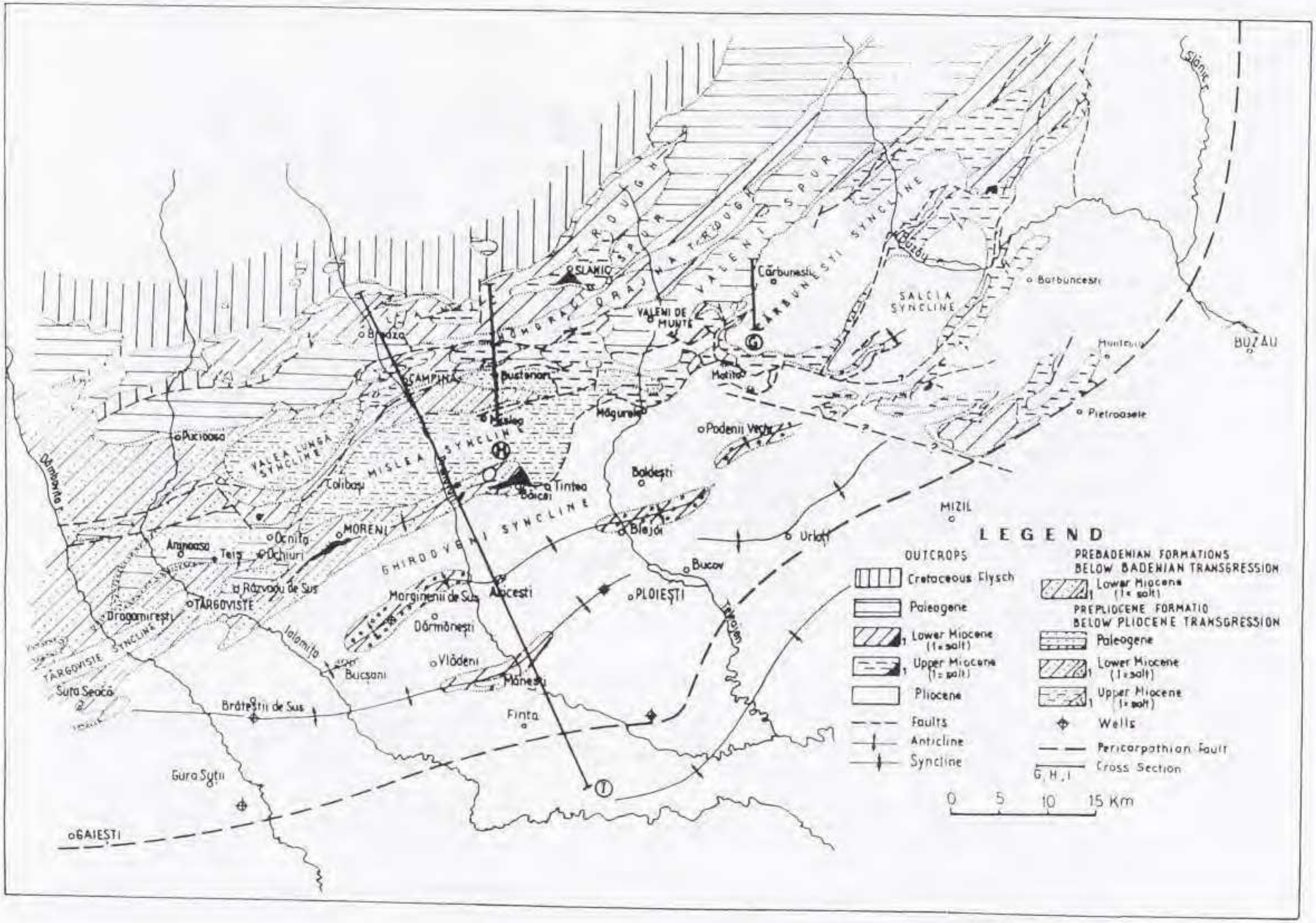
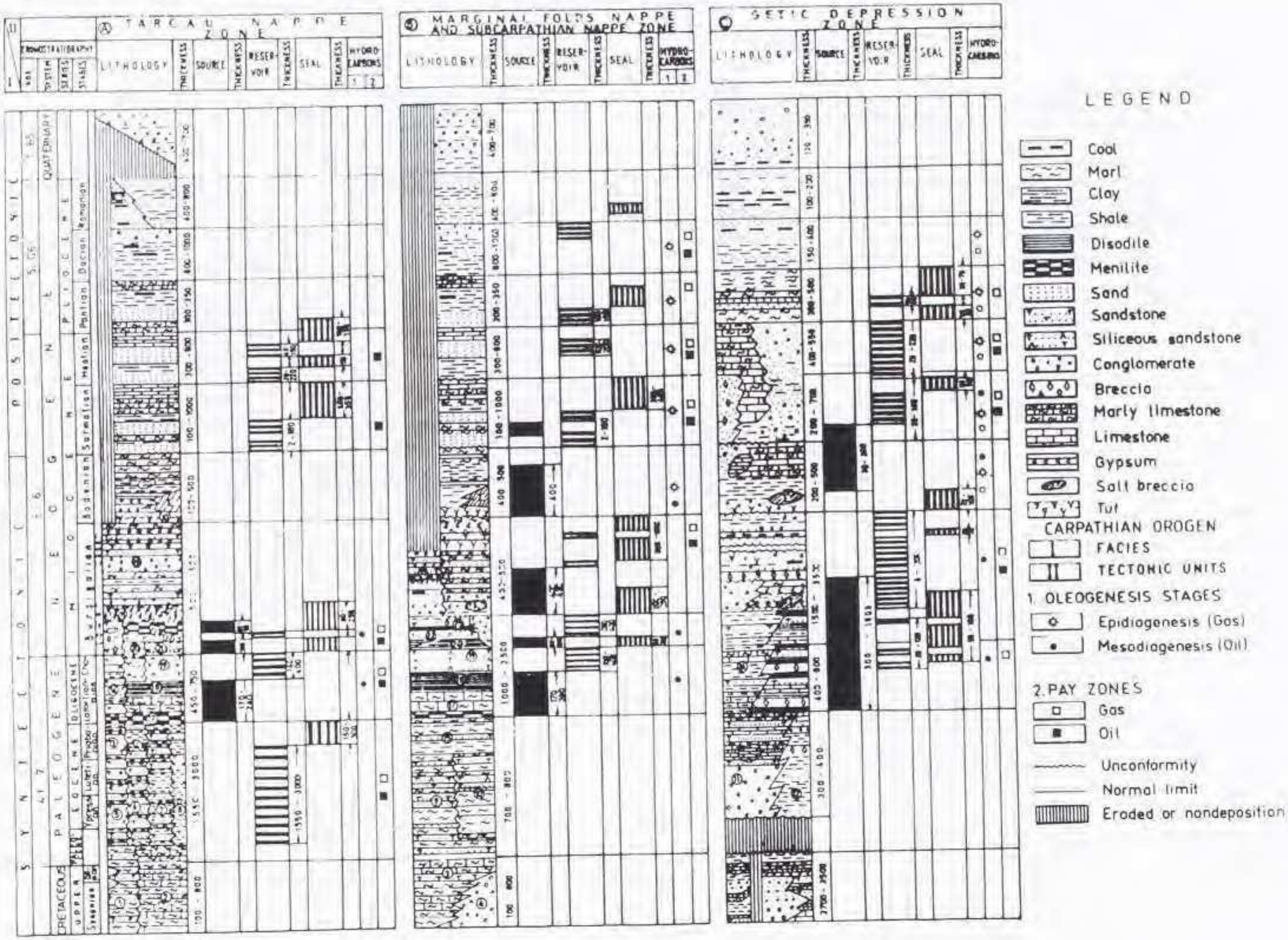


FIG. 9. Stratigraphic columns of Paleogene Flysch Zone, Mio-Pliocene Zone and Getic Depression. Cretaceous: 1-Horgazu beds, 2-Hangu beds, 3-Casin beds, 4-Piatra Streiului conglomerates; Paleogene-Miocene: 5-Tarcau sandstone, 6-Intermediate facies, 7-Colti facies, 8-Lesunt beds, 9-Gresu beds, 10-Buciasu beds, 11-Sacel conglomerates, 12-Sotrile beds, 13-Podu Secu beds, 14-Plopu beds, 15-Bisericani beds, 16-Fusaru-Krosno facies, 17-lower Menilites and white bituminous marls, 18-lower Disodiles, 19-lower Kliwa sandstone, 20-Vinetisu beds, 21-Podu Morii beds, 22-upper Kliwa sandstone, 23-Upper Disodiles and Menilites, 24-upper Disodiles, 25-Goru-Misina(Gura Soimului) beds, 26-Pucioasa-Fusaru beds; Miocene: 27-Harja beds, 28-Cornu beds, 29-Brebu conglomerates, 30-Slanic tuff.



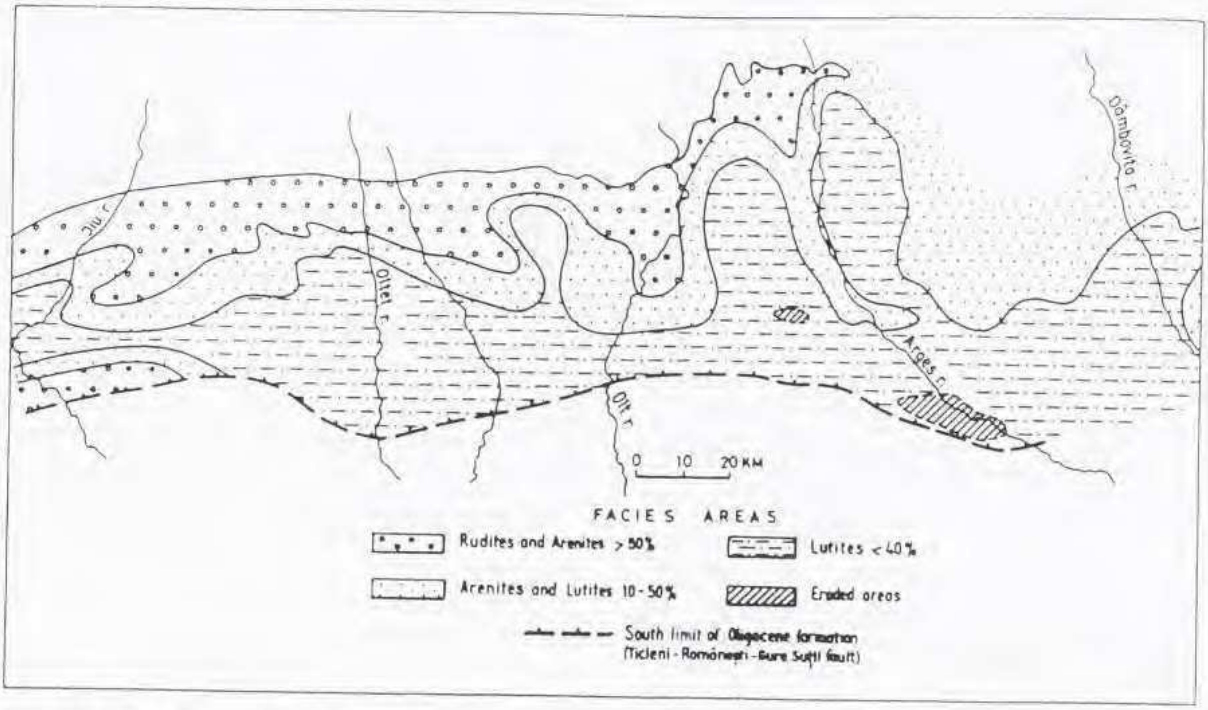


FIG. 10. Getic Depression. Lithostratigraphic map of Oligocene formations.

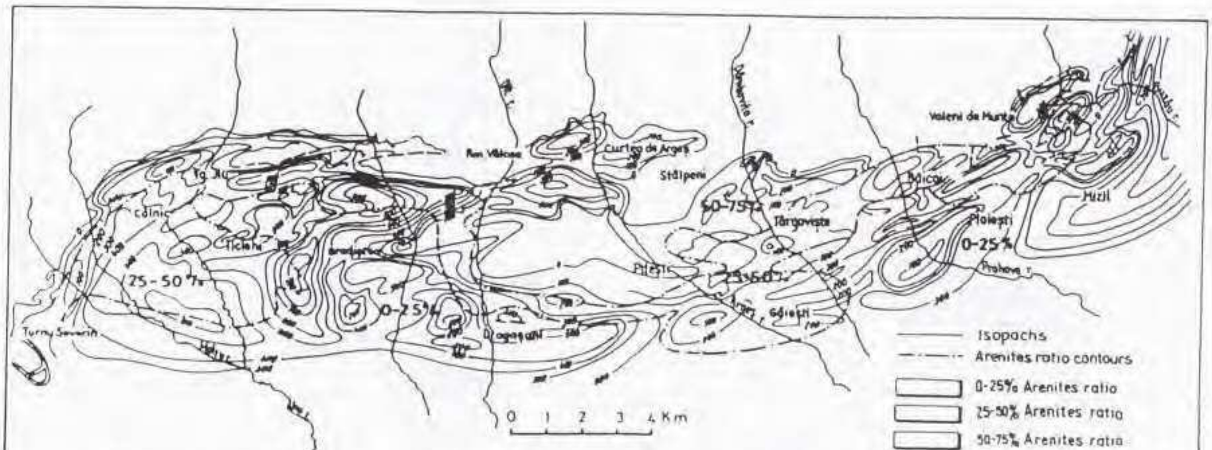


FIG. 11. Mio-Pliocene Zone and Getic Depression. Isopach map and sand/shale ratio of Meotian Formation. Sand/shale ratio in %.

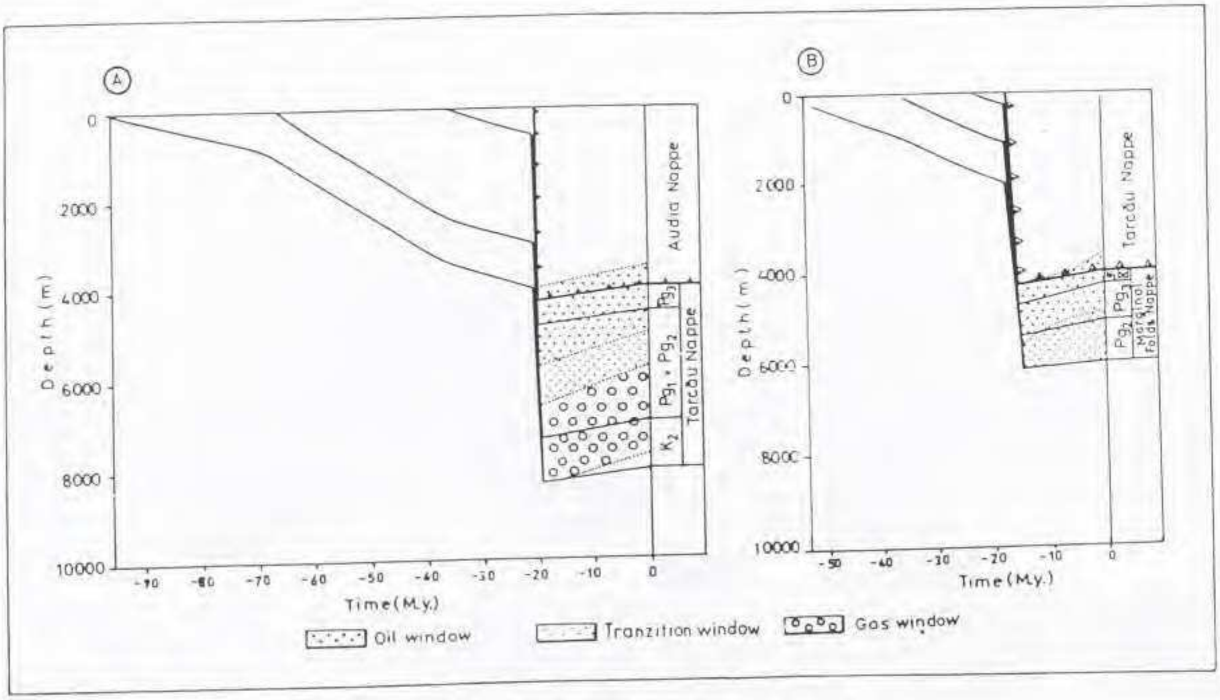


FIG. 12. Burial history and hydrocarbon kinetics diagram of Oligocene source-rocks from Tarcau (A) and Marginal Folds (B) nappes (kerogen type II-constant heat flow 50 mWm^{-2}).

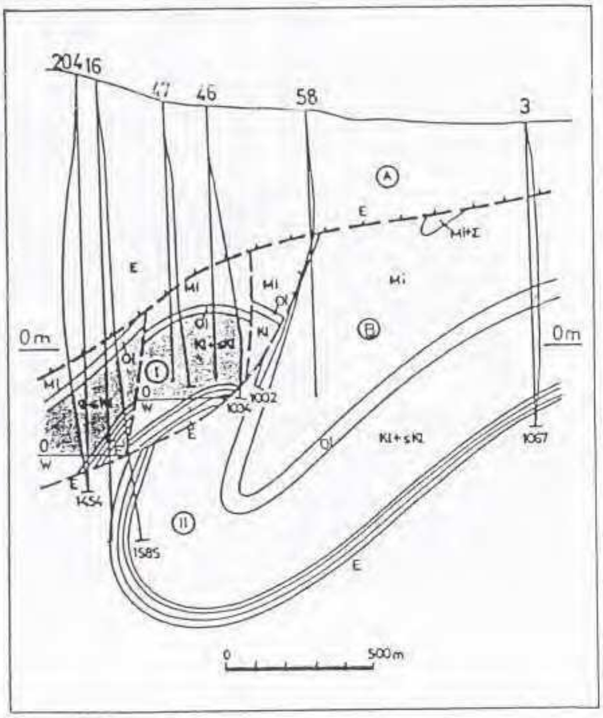


FIG. 13. Geamana oil field (for location see Figs. 2 and 5, trace B). A-Tarcau Nappe, B-Marginal Folds Nappe, I-First Scale Fold, II-Second Scale Fold, E-Eocene, O-Oligocene, Mi-Miocene, Kl-Kliwa Sandstone, SKl-Supra-Kliwa Formation (after Matei, 1973).

The sub-thrust continuation of these features was established by locating wells in the projection of established surface features and by limited reflection seismic data. The configuration of such sub-thrust Marginal Folds nappe structures varies from very steeply flanked anticlinal and thrusted features in the west to more gentle ones in the east. However, all features are characterized by a very complex internal configuration, as shown by the examples discussed below from the Tazlau-Oituz river area (Fig. 5).

The **Geamana oil field** (Fig. 13) is the westernmost productive structure of the Marginal Folds nappe occurring beneath the Tarcau nappe north of Trotus valley. In this field, the thickness of the latter ranges between 300 and 1000 m. The trap is formed by a complex faulted and thrusted fold, involving Eocene to early Miocene series. Production comes from the Oligocene Kliwa and Supra-Kliwa sandstones and the Gura Soimului beds. Additional pay sections occur in Eocene formations of the Tarcau nappe; these are in thrust contact with the Oligocene reservoirs of the underlying Marginal Folds nappe. The deepest wells were drilled to nearly 1600 m and tested two small thrust slices. Additional slices may occur at greater depths.

The **Zemes-Tazlau-Cilioaia oil field** (Fig. 14) is located at a few hundreds meters depth beneath a thin, complex zone of imbrications, attributed to the Tarcau and Marginal Folds nappes. Main accumulations are contained in two relatively gentle, though faulted and thrusted anticlinal structures. Producing intervals are Oligocene and Miocene sandstones. The sole-thrusts of tectonic slices covering this structure are only partly sealing, as indicated by the overspill of the western accumulation into the overlaying thrust slice. Pre-Oligocene objective have not yet been tested in the crestal parts of the trap-providing structures.

The **Pacurita oil field** (Fig. 15) was discovered at very shallow depths in the Tarcau, Tazlau and Marginal Folds nappes in an area where the Tarcau nappe is unconformably covered by Sarmatian sediments of the Comanesti basin. The Tazlau nappe is considered as a subunit of the Tarcau nappe. Production was obtained from Eocene reservoirs involved in the Tarcau nappe and from Oligocene reservoirs of the Tazlau and Marginal Folds nappes. In the Marginal Folds nappe, the

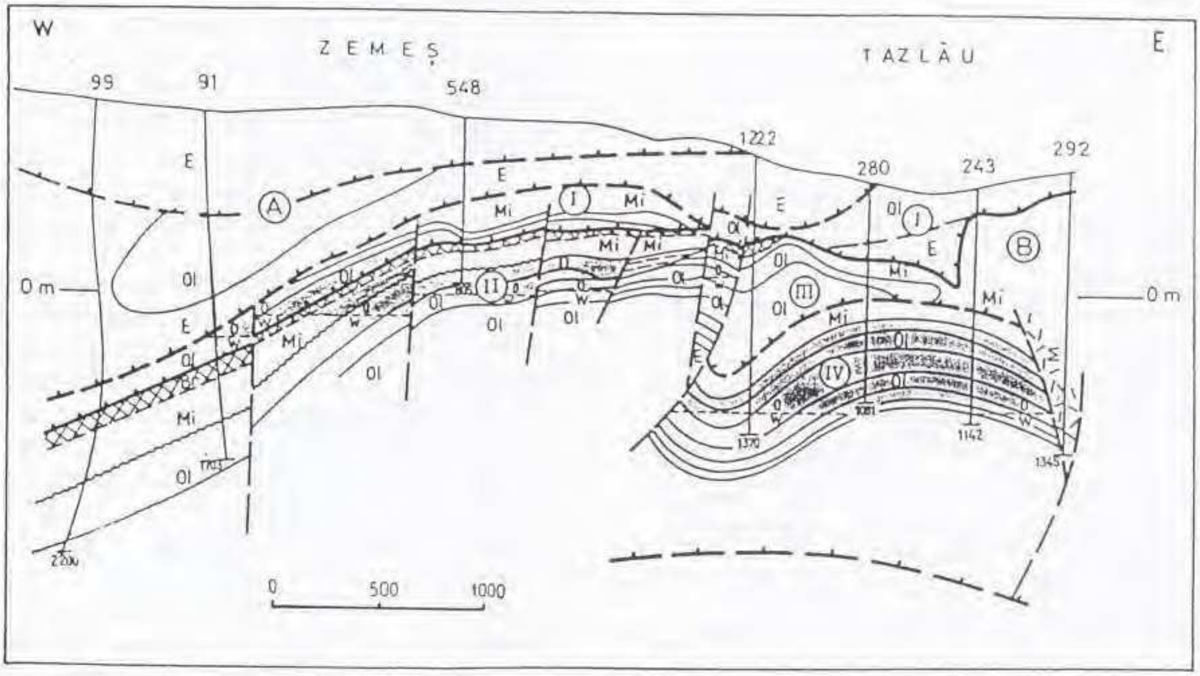


FIG. 14. Zemes-Tazlau-Cilioaia oil field, Marginal Folds Nappe (for location see Figs. 2 and 5, trace C). I-First Scale Nappe, II-Second Scale Nappe, III-Third Scale Nappe, IV-Fourth Scale Nappe (after Giurgiu et al., 1970).

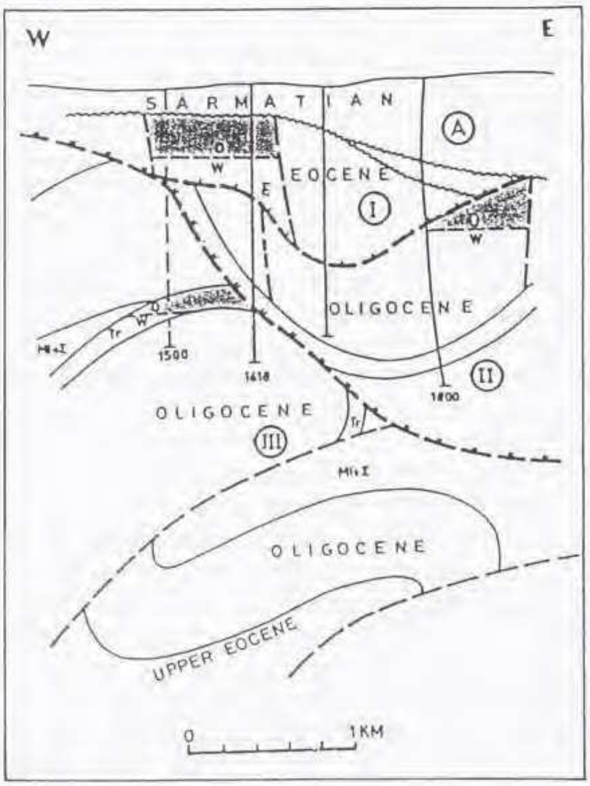


FIG. 15. Pacurita oil field (for location see Figs. 2 and 5, trace D). A-Comanesti post-tectonic Basin, I-Tarcau Nappe, II-Tazlau Subunit from Tarcau Nappe, III-Marginal Folds Nappe, O/W-oil-water contact (after Caminschi, 1973).

producing interval corresponds to the Gura Soimului beds; deeper objectives have not yet been tested. Deep seated imbrications of the Marginal Folds nappe are anticipated and may provide further prospects in this already productive, tectonically very complex area.

In the **Dofteana-Bogata oil field** (Fig. 16), wells spudded in the Sarmatian Comanesti Depression and the Tazlau unit of the Tarcau nappe, penetrated three thrust slices of the marginal units of the Tazlau nappe. The Marginal Folds nappe was not reached at depths of about 2200 m. Oil was discovered in Miocene and Oligocene reservoirs of the Tazlau nappe and its marginal thrust slices.

The southernmost discovery in the Bistrita-Trotus province of the East-Carpathian Flysch Zone is the **Ghelinta oil and gas field** (Fig. 5). It is located about 25 km to the west of the Tarcau nappe front and produces at a depth of 2100-2200 m from Kliwa sands involved in the Marginal Folds nappe. Discovery of this field proves that the thickness of the Tarcau nappe is variable and not everywhere prohibitive.

The definition of new prospects in the Marginal Folds nappe, both in a subthrust position beneath the Tarcau nappe and in tectonic half-windows of the latter, requires detailed reflection-seismic control. However, data acquisition is often hampered by a rugged relief. Nevertheless, results of previous exploration activity shows that hydrocarbon supply and reservoir risks are rather low for Marginal Folds nappe prospects. In parts of the northern East-Carpathians, the Marginal Folds nappe is poorly developed beneath the Tarcau nappe, rests behind the foreland threshold and is highly tectonized (Fig. 3); in this areas foreland structures offer the primary prospects.

Mio-Pliocene Zone

The Mio-Pliocene Zone comprises the southern and southwestern parts of the Subcarpathian, Marginal Folds and Tarcau nappes (Fig. 8). In this area, thick late syn- and in part post-orogenic molasse deposits cover the foreland, the Subcarpathian and the more internal nappes (Fig. 7, section I). The Subcarpathian nappe was emplaced during Sarmatian-Badenian times and was reactivated during the Pliocene Valachian phase (Dicea, 1995).

In the Suceava-Slanic valleys sector of the Subcarpathian nappe only few oil and gas accumulations were discovered. In this area, the Subcarpathian molasse nappe is superimposed on foreland formations and only few structurally closed traps could be established. Correspondingly, traps involving the foreland series play a more important role.

However, in the area delimited to the east by the Slanic of Buzau Valley and to the west by the Dambovita Valley, the Mio-Pliocene Zone hosts the most prolific hydrocarbon province of Romania (Fig. 7, section I and Fig. 8). Here, Oligocene and Miocene source-rocks were deposited in a continuously and strongly subsiding basin, characterized

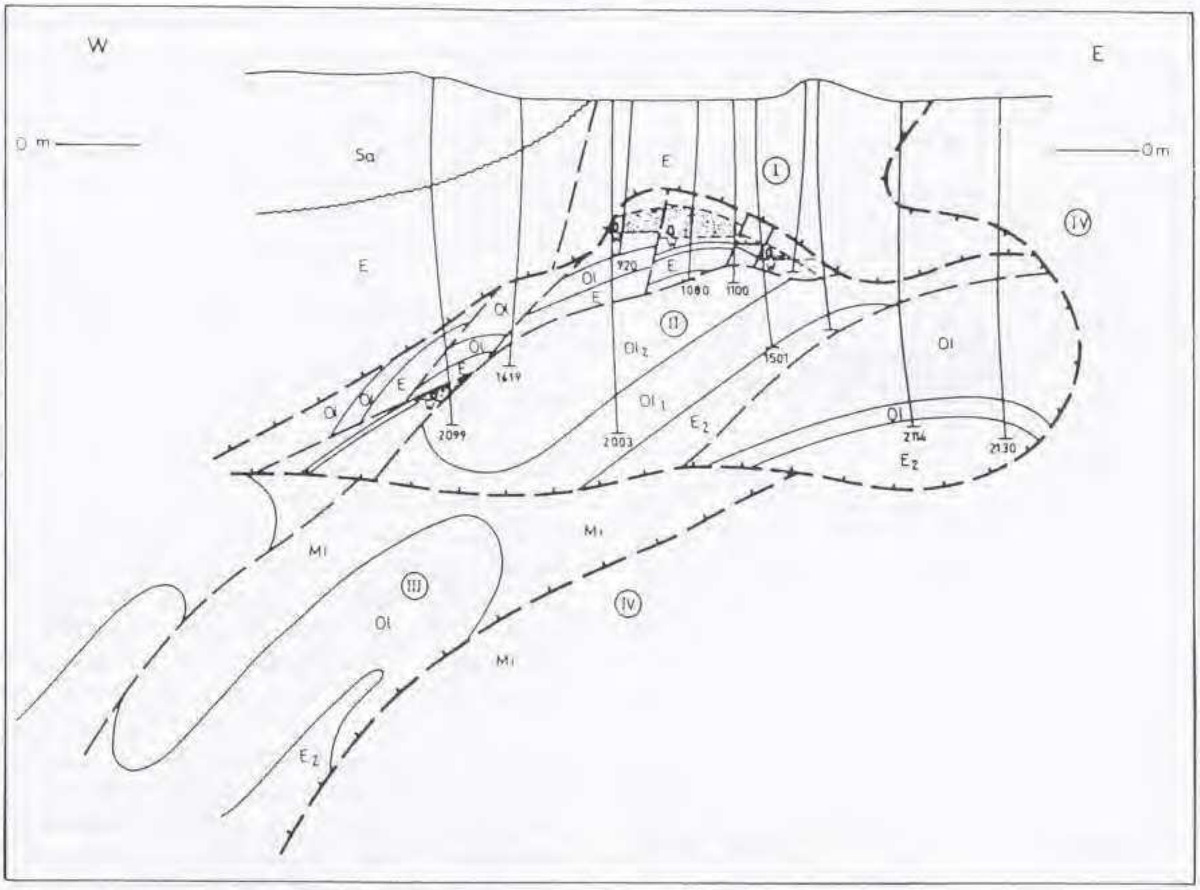


FIG. 16. Dofteana-Bogata oil field (for location see Figs. 2 and 5, trace E). I-Tazlau Subunit from Tarcau Nappe, II-Marginal Subunit from Tarcau Nappe., III-Marginal Folds Nappe, IV-Subcarpathian nappe (after Caminschi, 1973).

by a normal thermal gradient. In the structuration of this area, halokinetic mobilization of Burdigalian salt played an essential role during the accumulation of upper Burdigalian and Pliocene series. Involvement of the entire Paleogene flysch and Neogene molasse series in the intra-Pliocene Valachian compressional deformations have contributed to the development of most of the structural traps, some of which are cored by salt diapirs.

Main productive intervals occur in the Oligocene, lower and upper Miocene and Pliocene series (Meotian, Dacian and Levantin formations, Fig. 9). The Oligocene-lower Burdigalian Kliwa Sandstone is quartzous whereas the younger Miocene and Pliocene sands are calcareous. Oligocene productive horizons vary in thickness between 2 and 60 m (Bustenari field); Miocene sands range in thickness between 10 and 90 m (Teis field) and Sarmatian sands between 50 and 100 m (Boldesti field) (Table 1). Meotian sands are the main producer in the Carpathian Bend area. The Meotian formation contains productive complexes which change along strike in thickness from 125 m in the Barbuncesti field to 80 m in the Boldesti and to 34 m in Bucsani field and, in a dip direction, from 25 m in the Ocnita field to 40 m in the Moreni and to 50 m in the Finta field.

Involvement of the Mio-Pliocene molasse sequences in the Valachian folding phase is also responsible for the development of structural traps involving Oligocene and lower Miocene formations of the Subcarpathian, Marginal Folds and Tarcau nappes. The Tarcau nappe is involved in the Bustenari-Runcu anticlinal trend. In the Baicoi and Moreni structures, Oligocene series, forming probably a part of the Marginal Folds nappe, were intercepted. The front of the Paleogene Peri-

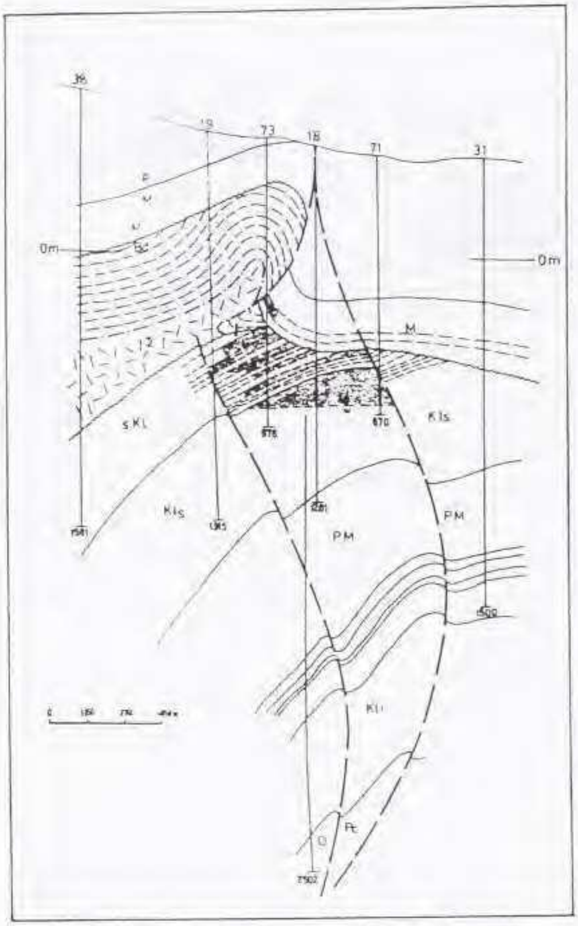


FIG. 17. Carbunesti North oil field (for location see Figs. 2 and 8, trace G). O-Oligocene, Bd-Burdigalian, M-Meotian, P-Pontian, SKI-Supra-Kliwa Horizon, Kls-upper Kliwa Horizon, PM-Podu Morii beds, Kli-lower Kliwa Horizon, Pc-Pucioasa facies of Oligocene.

carpathian nappe is probably associated with the Bucsani-Aricesti-Pietroasele-Monteoru alignment (Fig. 8; Dicea, 1995).

Oil and gas accumulations, reservoired in Oligocene and Miocene sands, are contained in structural traps, such a thrusted anticlinal features (Runcu, Gura Ocnitei fields), diapiric folds (Baicoi, Moreni, Bucsani fields) and faulted and unfaulted anticlines (e.g. Boldesti, Margineni, Podeni fields), as well as in stratigraphic traps associated with the basal transgressive surface of the Meotian formation (e.g. Carbunesti, Runcu-Bustenari, Campina, Margineni fields). This shows that these hydrocarbon accumulations have formed only after the Valachian deformation phase, that is, during the late Pliocene and Pleistocene.

Well data from the Carbunesti oil field (Fig. 17), which produces from Oligocene, Burdigalian and Meotian sands, give evidence for the two-phase development of this structure. The basal Meotian unconformity truncates Oligocene and Miocene series and was itself deformed during the Valachian compressional phase. The trap is provided by a folded and faulted unconformity surface and the presence of thick Burdigalian salt on the western flank of the structure.

The **Bustenari-Runcu oil field** (Fig. 18) is contained in complex imbrications of the Tarcau nappe, involving Oligocene and Burdigalian strata, truncated by the basal Meotian unconformity, which in turn was folded and faulted during the Valachian deformation phase. At shallow levels, production comes from Meotian, Burdigalian and Oligocene sands. A deep seated imbrication, involving Oligocene reservoirs, is also productive.

In the central part of Mio-Pliocene Zone, the most important structural trend is formed by the well-known diapiric Tintea-Baicoi-Moreni trend (Fig. 8). This structure, which is limited to the north and south by two large synclinal trends (Fig. 7, section I), contains the largest reserves of the entire Eastern Carpathians. Deep wells drilled during the last years on the Baicoi (7025 m), Moreni (5500 m) and Runcu (3600 m) structures proved the presence of Oligo-Miocene objectives and oil shows at deep and ultra-deep levels. However, poor reflection-seismic resolution of structural prospects at these depths has so far hampered exploration efforts (Dicea, 1995).

New targets in the Mio-Pliocene Zone are deep structural traps involving Oligocene and Miocene reservoirs. Reservoir development and hydrocarbon charge appear to be assured; the main risk lays in the reflection-seismic definition of drillable structures. In addition, there is a potential for stratigraphically trapped pools along the flanks of the already drilled up shallow structures.

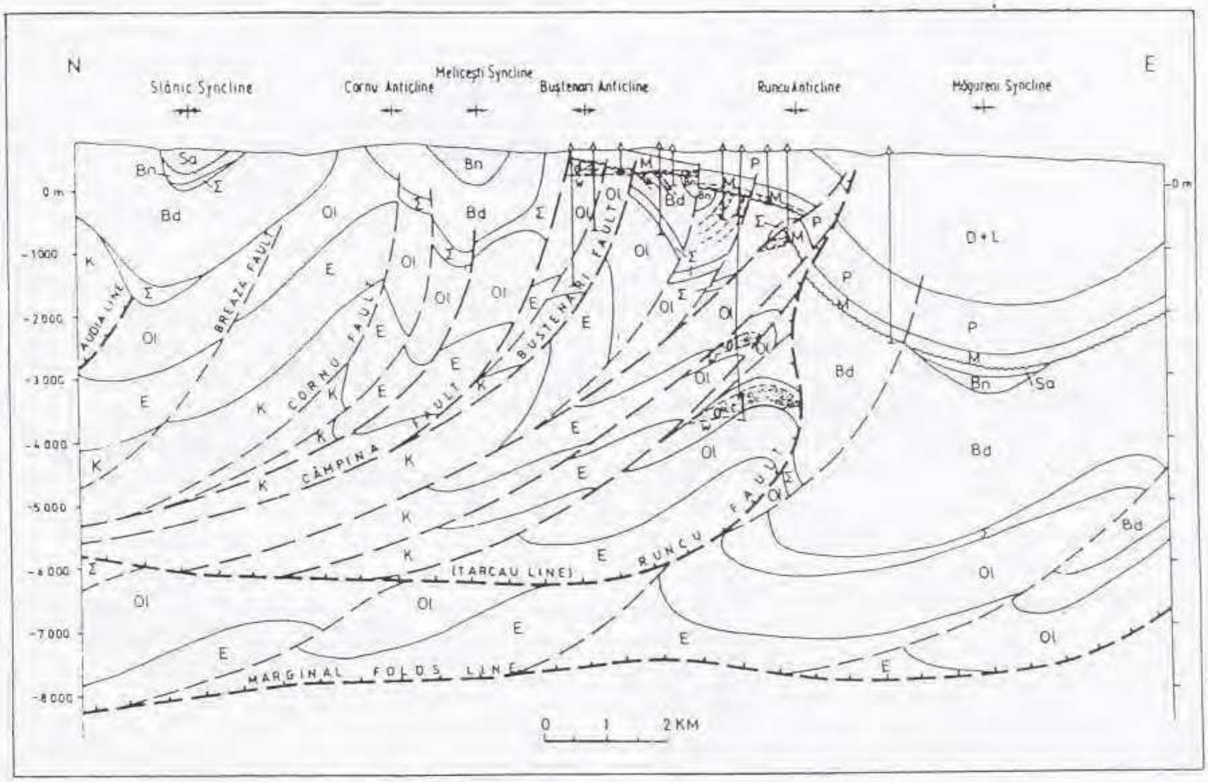


FIG. 18. Bustenari-Runcu oil field and deep prospects (for location see Figs. 2 and 8, trace H). K-Cretaceous, E-Eocene, O-Oligocene, Bd-Burdigalian, Bn-Badenian, Sa-Sarmatian, M-Meotian, P-Pontian, D+L-Dacian+Levantin, S-salt (modified after Albu et al.,1982).

Getic Depression

The Getic Depression corresponds to the South Carpathian foreland basin which is filled by Eocene to Pliocene molasse-type series, deposited on Mesozoic carbonates and Palaeozoic series of the Moesian Platform. The area was affected by the Older and Younger Styrian and the intra-Sarmatian Attic deformation phases. Along the Pericarpathian fault, which delimits the deformed area to the south, Lower and Middle Miocene strata are overthrusting Lower Sarmatian series. This fault is sealed by the onlapping and overstepping Middle Sarmatian to Pliocene molasse sequences (Fig. 7, section K).

The stratigraphic column of the Getic Depression is given in Figure 9. Eocene and Oligocene strata attain thicknesses of up to 5000 m in the northern parts of the Getic Depression and onlap southward the top-Cretaceous unconformity. Eocene calcareous sandstones and conglomerates grade upwards into a sandy marly section. Lower Oligocene sandstones ("Horizon-B") are followed by 300-800 m thick marls and shales, containing sand lenses ("Horizon-A"). The facies distribution of Oligocene series is summarized in Figure 10. Neogene strata reach thicknesses in the order of 2000 to 3000 m; they contain major lower Burdigalian and middle Badenian salt intercalations. During the Miocene the southern parts of the Getic Depression were overstepped.

The distribution of oil and gas accumulations in the Getic Depression is summarized in Figure 19. In the northern parts of the depression, where thick Paleogene sediments are present, Oligocene source rocks have entered under normal geothermal gradients in the oil window at depths of 3500-4500 m and have at present reached peak maturity (Fig. 20). The generated hydrocarbons migrated updip to the south and charged structural

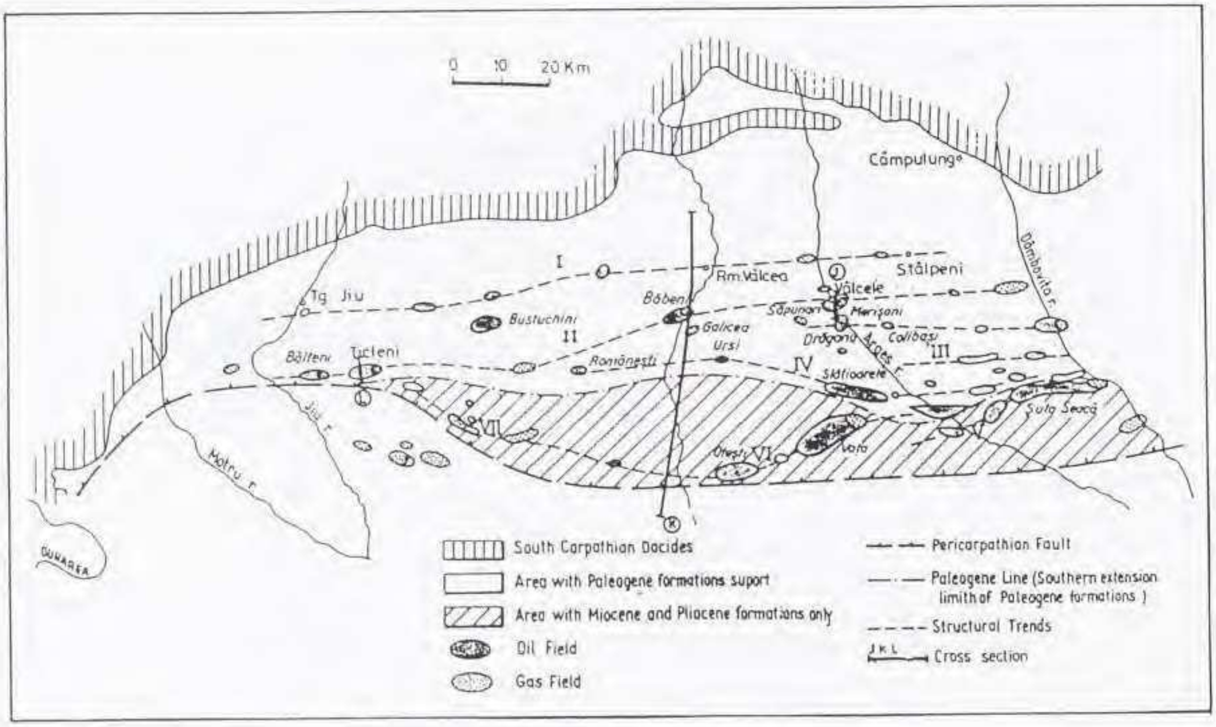


FIG. 19. Tectonic sketch and hydrocarbon pool alignments of Getic Depression.

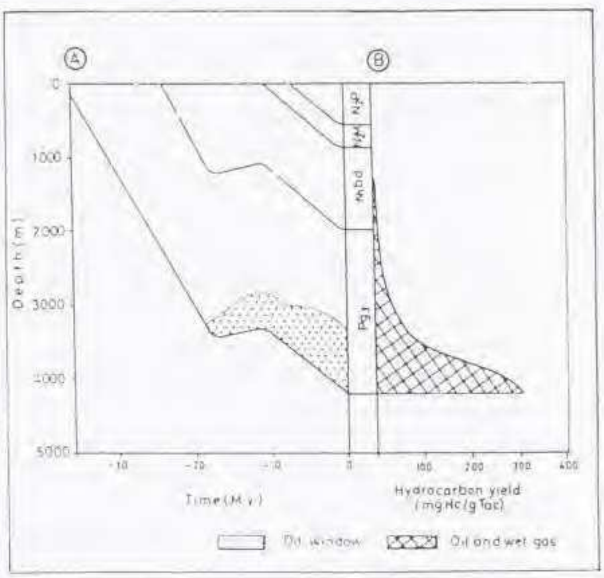


FIG. 20. Getic Depression. Burial history, hydrocarbon kinetics and yield diagram for Oligocene source rocks (kerogen type II, constant heat flow 46 mWm^{-2}).

and stratigraphic traps. Oligocene reservoirs are productive in a number of structures (e.g. Valcele, Merisani, Draganu, Sapunari). In Burdigalian to Sarmatian times, these structures developed during multiple deformation phases and were partly modified by Pliocene faulting. Fields are associated with the four distinct structural trends, designated in Figure 19 with the Roman numerals I to IV. In these fields production comes, apart from Oligocene sands, also from Burdigalian, Sarmatian and Meotian sands. Examples are the Valcele and Ticleni fields, both of which are located on trend II, well to the north of the Paleogene onlap edge.

The **Valcele oil field** (Fig. 21) produces from the Oligocene "Horizon-A" fan sands and from Burdigalian reservoirs. Structurally and stratigraphically trapped accumulations are associated with the basal Burdigalian and basal Badenian unconformities.

The **Ticleni oil and gas field** (Fig. 22) is contained in an anticlinal structure which grew during Sarmatian time and was modified by Pliocene faulting. Oil and gas pools are hosted in upper Burdigalian sands and Sarmatian and Meotian sand pinch-out traps.

In the external parts of the Getic Depression, which are situated to the south from the Paleogene onlap edge, Burdigalian series attain thicknesses of over 1000 m and contain sands with good reservoir properties; however, these reservoirs lack a hydrocarbon charge. In this area, Badenian, Sarmatian and Pliocene series attain thicknesses of over 4000 m south of the Pericarpathian fault and contain gas-prone source rocks intervals (Fig. 7, section K). These source rocks charged a number of gas fields on the structural trends V-VII (Fig. 19). Oil charge to these fields (e.g. Otesti), which are reservoired in Sarmatian, Meotian and Pontian sands, is presumably related to longer range migration from the northern parts of the Getic Depression.

CONCLUSIONS

The main hydrocarbon producing areas of the Romanian External Carpathians are the Bistrita-Trotus province and Carpathian Bend province of East-Carpathians and the Getic Depression of the South-Carpathians. All three areas are characterized by a deeply subsided autochthonous foreland which was thrusted under the Carpathian orogen.

In the Bistrita-Trotus province, the majority of fields produce from Paleogene flysch of the Marginal Folds nappe, involved in complex structures beneath the Tarcau nappe, generally in the vicinity of half-windows in the latter. Established fields are generally located at shallow depths. The potential of deeper seated structures is still poorly evaluated and requires the recording of extensive reflection-seismic surveys in a topographically difficult terrain. Oligocene-Early Miocene oil-prone source-rocks are well developed and provide abundant hydrocarbon charge to closely associated reservoirs; there are insufficient geochemical data to determine whether there is also a contribution from Cretaceous source-rocks.

In the prolific Carpathian Bend Zone, in which Mio-Pliocene molasse-type series are well developed and cover the Tarcau, Marginal Folds and Subcarpathian nappes, ample hydrocarbon charge is provided by Oligocene-Early Miocene and possibly Cretaceous source-rocks. Multiple reservoir-seal pairs are developed in Oligocene to Pliocene shallow marine deltaic series. Structural traps are associated with all nappe units. Unconformities, related to the different compressional phases, provide for additional traps. Most fields are contained in relatively shallow structures which attained their present configuration during the terminal Pliocene deformation phase. Deep wells indicate a good reservoir development at depth. Limited reflection-seismic data suggest the presence of deep-seated prospects requiring definition by extensive surveys.

The oil accumulations contained in Oligocene and Miocene reservoirs of the northern parts of the Getic Depression are closely related to the distribution of the Paleogene series containing mature source-rocks. The oil and gas accumulations of the southern parts of the Getic Depression are charged

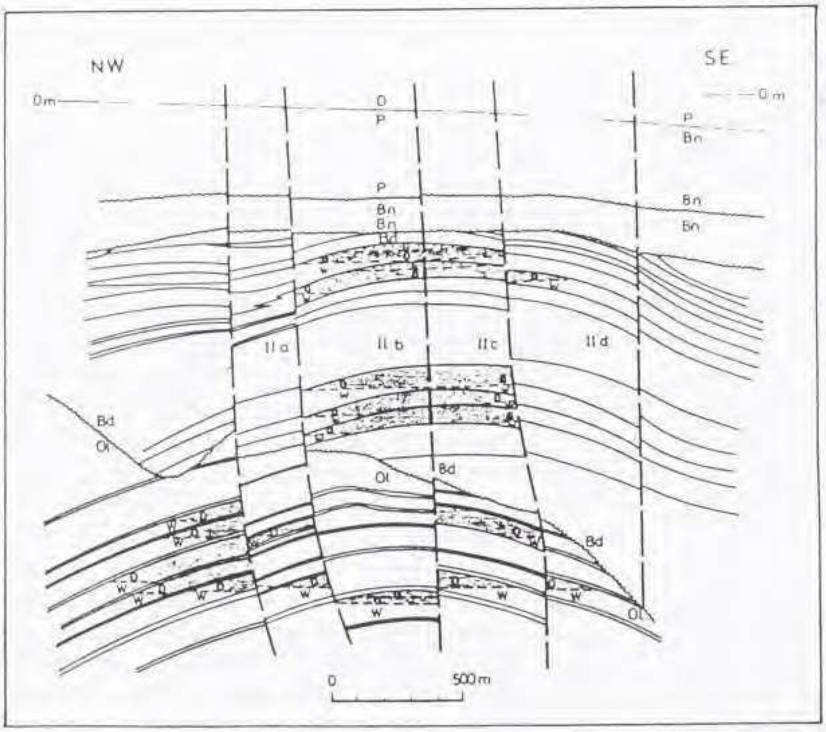


FIG. 21. Valcele oil field.(for location see Figs. 2 and 19, trace J) O-Oligocene, Bd-Burdigalian, Bn-Badenian, P-Pontian, D-Dacian, O/W-oil-water contact (after Popa, from Paraschiv, 1975).

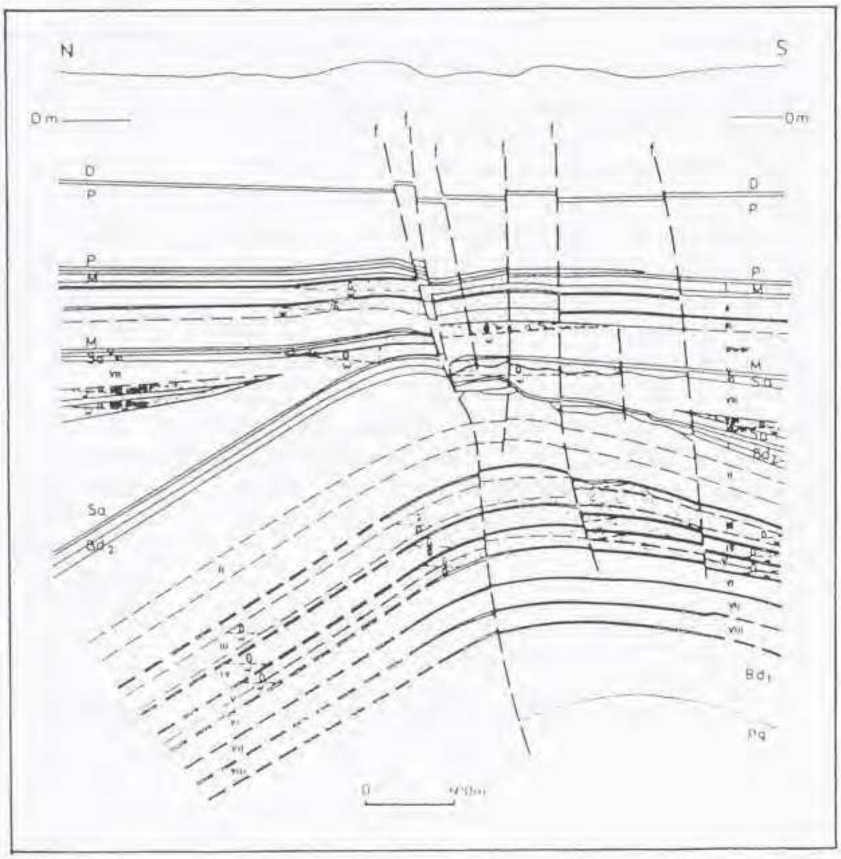


FIG. 22. Ticleni oil and gas field (for location see Figs. 2 and 19, trace L). Pg-Paleogene, Bd1-lower Burdigalian, Bd2-upper Burdigalian, Sa-Sarmatian, M-Meotian, P-Pontian, D-Dacian, I-VIII-producing horizons, F-Faults (after Ioachimciuc, 1970).

by gas-prone Mio-Pliocene source-rocks and are reservoired in late Miocene and Pliocene sands, involved in structural and combined stratigraphic/structural traps which developed during Mio-Pliocene deformation phases. In this area, the potential of deep seated prospects also requires further evaluation on the basis of extensive reflection-seismic surveys.

In the northern parts of the East-Carpathians, where the autochthonous foreland has not subsided to excessive depths, the Mesozoic sedimentary cover of the Moldavian Platform may host viable prospects. The deep Neogene Peri-Carpathian Focsani Depression hosts a number of gas accumulations. Similar accumulations may occur along the external flank of the entire Carpathian foredeep.

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